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SYSTEMS ENGINEERING APPLIED TO SELECTION AND REPLACEMENT OF SOLID WASTE COLLECTION VEHICLES FOR LAWRENCE, KANSAS

Kansas University

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A solid waste management open-file report (SW-4tg)

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U.S. ENVIRONMENTAL PROTECTION AGENCY

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SYSTEMS ENGINEERING APPLIED TO SELECTION AND REPLACEMENT OF SOLID WASTE COLLECTION VEHICLES FOR LAWRENCE, KANSAS

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U.S. ENVIRONMENTAL PROTECTION AGENCY

1971

I

An environmental protection publication
in the solid waste management series (SW-4tg).

II

FOREWORD

This Nation is facing the ever-growing problem of how best to manage its solid wastes. Not only are present practices of solid waste storage, collection, processing, and disposal becoming inadequate, but the United States also faces a shortage of trained professional workers in the field who are equipped to deal with the problem.

To help alleviate this shortage, the U.S. Environmental Protection Agency, under authority of the Solid Waste Disposal Act (Public Law 89-272), administers a program of grants-in-aid which supports graduate-level training programs at 13 universities for approximately 65 masters' degree candidates each year. These students receive specific training in the many aspects of modern-day solid waste technology and management. Some of these training programs are located at large urban universities and center their instruction on solid wastes in the urban environment, while other programs are at schools in agricultural regions and may place their emphasis on food-processing and farm waste problems. To date, over 100 engineers have been trained at the graduate level in universities receiving support from the Federal solid waste management program.

One phase of the graduate students' training is to conduct a research project dealing with a specific aspect of solid waste management. This document reports on the results of one such research project and provides information which should be useful to others concerned with better solid waste management practices.

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*Now the Office of Solid Waste Management Programs, U.S. Environmental Protection Agency.

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INTRODUCTION

This project as conceived by the author in cooperation with the Sanitation Department staff of the city of Lawrence is an attempt to apply the concepts of systems engineering to the problems of a real solid waste system. One of the major problems faced by the Sanitation Department deals with the selection and replacement of solid waste collection vehicles. Therefore, the primary purpose of this study was to apply systems engineering techniques to optimize solid waste collection vehicle selection and replacement. Because of finite time limitations, the scope of the study was limited to vehicles used for the collection and transportation of residential refuse. Another constraint placed on the study was that only collection vehicles that could satisfactorily comply with existing city and state highway loads limits and yet have only one rear axle were to be evaluated. The study was also limited to truck chassis and compactor bodies that were available and serviceable through dealers within 50 miles from Lawrence, Kansas.

Although the scope of this study is limited by the three previously mentioned constraints, it is felt by the author that these limitations are reasonable and valid in view of his experience and the type of evaluation performed.

Decisionmaking and Economic Relationships

Economic Decision Concepts

Economic decisions are constantly present in the daily activities of a solid waste system manager. Some decisions are of a brushfire nature; immediate answers are necessary for day-to-day problems. The approach to decisions of this nature are less sophisticated than to other types of decisions, but they nevertheless require knowledge and experience in the economic arena. Common sense by itself affords only a vague guideline for most economic decisions required of a manager of a solid waste system. To make sound decisions the manager must know the language and the rules of economic competition.

Therefore, it is important for the manager to know the quantitative guidelines for economic decisions.

A decision is simply a selection from two or more courses of action. Yet decision making can be an exciting, traumatic, or fascinating experience (1). Some choices are trivial or wholly automatic; others have far-reaching effects. Almost all major decisions have overtones of economy. Either on a personal basis or on behalf of his organization, a manager is constantly called upon to judge the most advantageous use for limited resources. A manager is a person skilled in administration and a major portion of this skill is necessarily applied to financial aspects.

Therefore, managers of solid waste systems constantly seek a practical and economical adjustment of means to ends that benefits service.

The manager thus strives for financial efficiency. Financial efficiency is a composite of many factors and can be expressed in general terms as output/input or worth/cost, where the output or worth is the revenue received from the services of the solid waste collection vehicles and the input

or cost includes operating expenses, depreciation expenses, interest on invested capital and other allied expenses. Because city government is a non-profit organization by its structure, the objective of a solid waste manager is to maximize service within given constraints and on the basis of economic criteria at a minimum cost.

Nature of Decisions

Decisions can be made either on the basis of intuition or analysis. The decision making sequence is as follows: a decision made at the present time is based on data from past performances and establishes a course of action that will result in some future outcome.

The analytical approach to decision making entails systematic study and quantitative evaluation of the past and future. Intutition is oriented in the present but informally embraces memories of the past and estimates of what may happen in the future (1). Both methods produce decisions and both have a place in the decision making process.

It is reasonable to assume that the analytical approach is more reliable, if for no other reason, because it takes more effort to conduct. Because of this effort many decisions are still made by hunches. Effort costs money and some minor decisions may not justify the expense. Even major decisions where analytical input is required have hunch aspects. Real world situations generally possess factors beyond the realm of current analytical techniques. Therefore, the analyst can go only so far before he must resort to judgment.

Intuition is freely flavored with instinctive judgment. Because of this it is a valid tool of the decision-maker, provided logic is not subdued by rules of thumb or unrecognized bias.

The two approaches can be set in perspective by stating analytical methods should be employed whenever they are technically feasible and economically justified. Beyond these limits, intuition and judgement are necessary and legitimate tools.

Procedures of Decisionmaking

Decisionmaking is an integral part of two worlds: the real everyday working world and the symbolic scientifically oriented world. Problems in managerial economy of solid waste systems originate in the real world of economic planning, management, and control. The problem is defined by information from the solid waste system environment. This data allows the analyst to formulate a hypothesis in symbolic terms. The symbolic language helps him convert the information to usable and effective forms. By experimenting with his abstraction of the real world, he can simulate various configurations of reality which otherwise would be too costly or inconvenient to investigate. From this activity a prediction hopefully comes forth.

The predicted behaviour is changed back to reality for testing in the form of hardware or commands. If it is sound, the problem is solved. If it is not, the cycle is repeated with the added information that the previous approach was unsuccessful.

A workable solution can not be guaranteed for any problem because some problems defy collection of data. Others seem to be too complex. Yet managers are expected to make decisions. The best approach to decisionmaking is a systematic attack on the problem. Systematic means a step-by-step logical procedure which consists of four specific steps: 1) definition of the problem, 2) collection of data, 3) formulating the model and , 4) evaluation. After the last

step is completed either there is a decision or no decision. With a no decision verdict the entire cycle may be repeated or more data may be needed and a new model formulated or the evaluation may show that just a new model is needed.

Defining the problem starts with an objective frame of mind. The decision-maker should be aware that explicit measures are necessary: an exact statement of objectives, information in the greatest quantity and of the best possible quality, correct application of appropriate analytical tools and the determination to conduct the analysis with efficient speed.

If a single objective satisfies the problem, an accurate statement is relatively easy. As the subdivisions and consequences of a problem become more numerous, the goals become more difficult to define. All objectives are limited by certain constraints; thus these constraints also become objective criteria.

Contradictory aims and nebulous goals result in confusing objectives (1). Likewise double standards and indefinite objectives lead to second guessing. An exact statement of realistic goals simplifies the entire decision-making process and is essential to effective decisionmaking.

In a preliminary search for a solution it may be useful to list all possible courses of action (1). The goal of such an approach is to identify alternatives that might otherwise be overlooked. Descriptive names for wholesale idea accumulation methods which encourage individual creative effort are brainstorming and skull sessions. While it is important to search for novel means of accomplishing something, it is equally important to recognize practical limitations. For each individual it is a personal and often troublesome question for each individual to decide whether the restrictions he imposes are real or imaginary.

Data act as fuel for decisionmaking and must be of

good quality if the analytical process is to function properly and smoothly. The different steps in the decisionmaking process rely on data, and none of the steps can compensate for poor data.

Sources of data are generally abundant, but reliable sources of data are less plentiful.

Current data are used to predict the outcomes of alternative courses of action. In decisions assuming certainty the outcomes are calculated directly from the input data. When the aspect of risk is included, current data must be extrapolated into the future to provide estimates of what could happen if a given course of action were followed. These estimates are usually called payoffs; however, a payoff may result in either a favorable gain or a marked loss depending on the competition for a particular project or proposal. As objectives reach further into uncertainty, the estimation of outcomes is proportionately more demanding. Thus high quality data and its careful inferential treatment are even more greatly needed.

Certain factors in the decision situation which cannot be translated into dollars with accuracy are called intangibles. The distinction between tangible and intangible factors is the ease and accuracy by which data are quantitatively expressed (1). Some quantitative measure can be imposed on most factors by applying enough resources. The question then is one of balancing the effort against the worth. All decisions have some intangible aspects - emotional gratification engendered by a certain course of action, safety considerations, the influence on personnel, reputations, friendships, public relations and so forth (1). Aspects of this type and similar ones are bound to enter the decision process either as identified intangibles or as vague impressions.

Although a manager can attempt to quantify intangibles, first all of them must be identified. However, whether intangibles are quantified it is the decision-maker's duty to

recognize that intangibles influence a decision just as persuasively as tangible factors.

Model Formulation

A model is a representation of the real world. Formulation of a model begins when one develops objectives and alternatives. The model depicts the relationship between cause and effect, between objectives and constraints. It is controlled to show the end product we can expect from following a given course of action. Models that can be used in the decisionmaking process fall into three classes: physical, schematic, and mathematical. Because this is an economic study, only mathematical models will be considered; however, the other two classes are also effective aids in special situations.

Equations and formulas are common mathematical models. They are more exact and less likely to be misconstrued than the other classes of model. Mathematical models are applicable in solving a wide range of problems.

In decisionmaking situations, the manager can use mathematical models to predict outcomes and to determine the measure of existing operations. In all model applications, the manager is still formulating a model in the abstract world to represent conditions in the real world.

Model Evaluation

The worth of a model is determined by its effectiveness in representing the real world. The true test of predicted behavior comes when the predictions are exposed to reality. Pretesting a model and evaluating the results is a confidence building precaution. The frankness of a model can be checked initially by applying it to historical data.

Methods for assessing the effectiveness of mathematical models usually consist of rules, algorithms and decision criteria. A good model with quantified data contributes to a complete analysis by making it easier to see the outcomes

resulting from different inputs and by making more time available for the decisionmaker to concentrate on intangible factors. After all the decisionmaking procedures are employed, the final authority is still the manager. He must evaluate the accuracy and reliability of his information and model. He must temper the model's prediction with any pertinent intangible considerations. Then he has to observe his decision as it is tested in the unforgiving real world.

In some decision situations the direct evaluation of available data will yield a solution. The characteristics of such decisions are inferred by their suggestive title, primary comparisons. Primary indicates a condition of immediacy. All the influencing factors of the decision environment are already present. Certainty is assumed. Comparison indicate that the value of two or more alternatives be weighed. A valid comparison is possible only if the outcomes of the alternatives are essentially equivalent (1). Thus, primary comparisons lead to a decision between alternatives with equivalent outcomes.

In the analytical approach to problem solving, outcome scales or decision weighing models can be used to express preferences among outcomes. The more useful rating scales possess mathematical properties which describe the problem and allow an evaluation. Some tangible factors defy such scaling and thus cannot be quantified. Therefore, it is important to realize that two types of scales, qualitative and quantitative, exist. Although there are various types of rating scales, namely ordinal scale, internal scale, ratio scale, mixed rating scale, a ratio scale comparison will be used in this analysis to evaluate the selection of new collection vehicles.

Ratio scale comparisons are the most useful and widely used rating systems. They use desirable properties from other

rating scales plus they employ an absolute-zero point and have the notable property of additivity. Measurements of weight, length and money are common ratio scales used by all. Because of daily exposure to ratio scales, this means of rating is a comfortable experience. Direct measurements of weights and lengths provide the basis for many decisions in both the real world and the symbolic world. (1). Measures of weights and length are also used in some economy studies, but the most common practice is to translate all the measures to monetary values whenever possible. In this study through the use of a ratio scale decision model called DARE, an acronym for Decision Alternative Ration Evaluation, various criteria were used to select a solid waste vehicle chassis and compactor body. This technique as explained by its author in an article as reprinted from the February, 1970 issue of American City is listed in Appendix A. This technique proposes a new method of decisionmaking through use of a rational, orderly process in scoring alternatives. The technique and its use is demonstrated in part III of this study.

Economic Life and Depreciation Concepts

The economic life of an asset is the number of years of use that minimizes the equivalent annual cost of holding the item (1). The service life or ownership life is the actual number of years the asset is kept. Frequently an asset's life can be estimated from an analysis of past performances of similar assets with references to current conditions and to the suggested life recommended by the Bureau of Internal Revenue.

Although the City does not pay income taxes, information relevant to income taxes and depreciation is important to understand. Depreciation expense has been recognized as a legitimate deduction from income in the U.S. for the past 125 years.

Depreciation can be defined as the decrease in value of physical properties with the passage of time. It is a fact that must be recognized by cities as well as business. Although it is easily recognized, the determination of its magnitude is far from easy.

Because property decreases in value, the process of depreciation results in a consumption of the values in these depreciable capital investments. Primarily it is necessary to consider depreciation for two purposes (3).

1. To provide for the recovery of capital that has been invested in physical property
2. To enable the cost of depreciation to be charged to the cost of producing products or services that are produced by use of the property.

Some of the reasons for capital consumption and the resulting depreciation are as follows:

1. Physical deterioration of the equipment. Such deterioration results from normal usage, because of the action from physical and inherent elements, and

because of accidental damage.

2. New production or service requirements. The service requirements of equipment may be increased beyond its capacity. These increased requirements may be in the form of higher quality standards or larger required capacities.
3. Development of improved equipment. Improved equipment are discovered which will perform the same operation less expensively.
4. Obsolescence of equipment by technological advances. The service performed by the equipment is no longer required. Although this fact does not appear to be valid for a rear loading solid waste collection vehicle at this time it certainly must be considered in view of the technological advances that have been made within the past decade in certain areas of the materials handling fields.
5. Inflation or monetary depreciation. An increase in price levels is a subtle but troublesome cause of depreciation. Yet at this time in our nation inflation is not only present, but it is pushing the price for equipment and vehicles up at the rate of 5 - 10% per year. Standard accounting practices relate depreciation to the original price of an asset, not its replacement. If prices rise during the life of collection vehicle, a comparable replacement becomes more expensive. This means that the capital recovered will be insufficient to provide a suitable substitute for the deteriorated asset. Because the depreciation is actually occurring to the invested capital representing the asset instead of to the asset itself, monetary depreciation is very difficult to estimate.

Since taxes are paid on net income, the manner in which depreciation charges are spread over the life of the asset has a definite effect on income taxes. The pattern of depreciation deductions is established by two factors: the length of life used in calculating depreciation and the method chosen for prorating year-by-year depreciation costs over the selected life. Lives considered reasonable on the basis of averages and past performances by the Bureau of Internal Revenue for general purpose trucks varies from four to six years. Since refuse collection work could by nature be classified as moderately severe duty, one could probably use a useful life of four or five years. A conservative approach would indicate the use of a four year average service life. The guidelines suggested by Internal Revenue should be considered only as guidelines. If it is apparent that the economic life of a collection vehicle is longer or shorter than the suggested guideline, the best estimate should be used. This estimate should be based on an analysis of accurate data and current conditions.

Behind all the guides and suggestions for estimating economic life management may have a basic philosophy that often prejudices the actual selection. From one view it is desirable to keep a vehicle in operation as long as possible because average annual capital recovery costs will be lower. From another view it is a drive to minimize the chance of losses from inferior quality or inefficient operation due to a prolonged life estimate. When these opposing views are additionally colored by personal attachments for certain brands of equipment or a desire to always have the most modern equipment, life estimations get very twisted.

Concurrent with the identification of a collection vehicle economic life is the choice of a method to determine the annual charge for depreciation. In general, the

desirable features of a depreciation method are that it (1) recovers the capital invested in an asset, (2) maintains a book value, which is the original cost of the asset minus the accumulated depreciation reserve, close to the actual value of the asset throughout its life, (3) is easy to apply, and (4) is acceptable to the Bureau of Internal Revenue. Although there are various depreciation methods available, only four are widely used. They are:

Straight-line method
Sum-of-the-year's-digits method
Declining-balance method
Sinking-fund method

All of the above methods are based strictly on time. That is, a collection vehicle used every day has the same depreciation charge as one used only once a year. Because of this clear inequity some persons advocate that depreciation should be based on the amount of use as well as economic life. It is possible to combine a usage factor with a time-related method such as straight-line depreciation to reflect the change of decreasing value with use. This technique is acceptable where it can definitely be shown that the useful life is a function of the rate of service or production. However, for most property it is not possible to obtain the required use information with any degree of accuracy, and therefore the method is not considered generally applicable.

Each of the major depreciation methods has unique features which appeal to different management philosophies. Methods such as the declining-balance or sum-of-the-years'-digits method by which the bulk of the money invested is recovered early in the life of the vehicle is a popular conservative view. A method by which the annual charge is constant such as straight-line simplifies the accounting procedure.

Although an extensive review of current resale values of collection vehicles was not performed, there is enough information available to indicate that the truck chassis part of the collection vehicle depreciates at an accelerated rate similar to the sum-of-the-years'-digits or declining-balance method. Therefore if the City wants to maintain the book value of their vehicles close to the actual value throughout their life it would be advisable to investigate the use of one of these depreciation methods. The sum-of-the-years'-digits method is easier to apply than the declining balance method and would be preferred to the other method if it gives an accurate representation of the vehicle's actual value.

The City currently uses the straight-line method for equipment depreciation. It is desirable because of its constant annual rate of depreciation and it is the simplest to apply. Because of these features it is the most widely used. To illustrate the features, advantages and disadvantages between the straight-line and sum-of-the-years-digits method I will use a sample problem.

Depreciation Analysis Sample Problem

Given: Solid waste collection vehicles purchased by the city cost $15,000 each. Past records indicate the trucks should have an economic life of 5 years. After 5 years of use the vehicles can be sold for an average of $1,500. The City currently receives 6% interest on invested funds.

Determine: a) The depreciation charges during years 1, 2, 3, 4 and 5.
b) The book value at the end of year 3.

Depreciation formulas, symbols and information:

Income taxes will not be considered in this sample problem analysis because the City is exempt from federal income taxes. The symbols used in the development of the formulas are:

P = purchase price (present worth at time zero) of the equipment

S = salvage value or future value at the end of the equipment's economic life. The salvage value is positive if the item is resold or scrapped, zero if it is discarded at no cost, or negative if removal costs exceed resale value

n = economic life in years. Since obsolescence is a prime factor in depreciation, it is apparent that the physical life of the equipment is often not the life that must be considered in establishing depreciation rates. Generally the economic life, which is the length of time that the equipment will probably

be operated on an economical basis, is more applicable

N = number of years of depreciation or use from the time of purchase

i = interest rate received on invested capital

1. Straight-line method: Straight-line depreciation is constant thus the following relationships apply:

$$d = \frac{P-S}{n} = \text{annual depreciation charge}$$

$$V_n = P - \frac{N}{n}(P-S) = \text{book value at end of year N.}$$

Solution: $d = \frac{P-S}{n} = \frac{15,000 - 1500}{5} = \$2,700$ per year

V_3 = Book value at the end of year 3 = $P - \frac{N}{n}(P-S)$

$= 15,000 - \frac{3}{5}(15,000-1500)$

$= 15,000 - \frac{3}{5}(13,500) = \$6,900$

2. Sum-of-the-Years'-Digits Method: This method provides a larger depreciation charge during the early years of ownership than in the later years. The depreciation factor in any year of life corresponds to the number of each year of life when the number of each year is listed in reverse order and divided by the sum of the digits. For example:

Year	Number of Year in Reverse Order (Digits)	Depreciation Factor
1	5	5/15
2	4	4/15
3	3	3/15
4	2	2/15
5	1	1/15

The annual depreciation charge is the product of the depreciation factor for that year and the depreciable value, P-S. This gives

$$d = \frac{n-N+1}{1+2+3..n}(P-S) \quad \text{or} \quad d = \frac{2(n-N+1)}{n(n+1)}(P-S)$$

$$d_1 = \frac{5-1+1}{15}(15{,}000-1500)$$

$$= 5/15\ (13{,}500) = \$4{,}500$$

$$d_2 = \frac{5-2+1}{15}\ (13{,}500) = \$2{,}800$$

It is readily seen that the annual depreciation charge decreases each year from a maximum the first year.

The book value, V_n, at the end of a given year represents the purchase price, P, minus the cumulative annual depreciation charges. It can be represented by the following formula:

$$V_n = \frac{P-2[n+(n-1)+..N]}{n(n+1)}\ (P-S)$$

$$V_3 = 15{,}000 - \frac{2[5+4+3]}{5(6)}\ [15{,}000-1{,}500]$$

$$= 15{,}000 - \frac{12}{15}\ (13{,}500)$$

$$= \$4{,}200$$

3. Comparison of Depreciation Methods

A comparison between straight-line and the sum-of-the-years' digits depreciation throughout the assumed economic life (Table 1 and Table 2) is worth analyzing to show the difference in book value of the vehicle.

Table 1

Straight-line Depreciation Method

Year	Book Value at Beginning of Year	Depreciation Charge in Year	Book Value at End of Year
1	15,000	2,700	12,300
2	12,300	2,700	9,600
3	9,600	2,700	6,900
4	6,900	2,700	4,200
5	4,200	2,700	1,500

Table 2

Sum-of-the-Years'-Digits Depreciation Method

Year	Book Value at Beginning of Year	Depreciation Charge in Year	Book Value at End of Year
1	15,000	4,500	10,500
2	10,500	3,600	6,900
3	6,900	2,700	4,200
4	4,200	1,800	2,400
5	2,400	900	1,500

4. Equivalence of Methods When Interest Charges are Included

If one considers the time-value of capital in the depreciation method analyses some interesting equivalence relationships develop. Usually interest charges are not included in straight-line or sum-of-the-years' digits depreciation methods. However, if the return on the invested capital is included, the different depreciation mehtods share a common equivalent annual cost. An example will be used to point out this relationship (Table 3). The return may be thought of as the "profit" that would result if the undepreciated portion of the funds for an asset were invested at the suggested rate of return.

Table 3
Capital Recovery Plus Return at 6% Interest
Straight-line and Sum-of-the-Years'-Digits Depreciation

Year (N)	Book Value at Beginning of Year (1)	Return on Uncovered Capital at 6% Interest 0.06x(1) (2)	Depreciation Charge in Year (3)	Capital Recovery Plus Return (2)+(3) (4)	Present Worth Factor @6% (5)	Present Worth of Payment (4)+(5) (6)
1	15,000	900	2,700	3,600	.9434	3396
2	12,300	738	2,700	3,438	.8900	3060
3	9,600	576	2,700	3,276	.8396	2750
4	6,900	414	2,700	3,114	.7921	2467
5	4,200	252	2,700	2,952	.7473	2206
			Total present worth of straight-line payments			13,879
			Sum-of-the-Years'-Digits Depreciation Method			
1	15,000	900	4,500	5,400	.9434	5094
2	10,500	630	3,600	4,230	.8900	3765
3	6,900	414	2,700	3,114	.8396	2615
4	4,200	252	1,800	2,052	.7921	1625
5	2,400	144	900	1,044	.7473	780
			Total present worth of sum-of-the-years'-digits payments			13,879

The return of the unrecovered capital is based on the book value at the beginning of each year and an interest rate that the City expects to receive if the money was invested. If the depreciation charge for each year is added to the return on unrecovered capital for that year, this gives the total annual cash flow for capital recovery plus return. The annual single payment present worth factor is used to translate the periodic cash flow to an equivalent single value at time zero.

The present worth by both depreciation methods is $13,879. It must be recognized that a present worth of $13,879 results from a fictitious interest charge on the unrecovered capital. Actual depreciation practices seldom include this charge, but it is applied in this example to show the different depreciation patterns are equivalent from a time-value standpoint based on investment returns rather than operational considerations.

Since the depreciation methods are equivalent in the time-value of capital, it is possible to use one formula to account for the capital recovery investment returns of any piece of equipment as follows:

$$CRD = (P-S)(CRF\text{-}i\%\text{-}n)+(S)(i\%)$$

where CRD = equivalent capital recovery depreciation charge

CRF - i%-n = capital recovery factor $= \frac{i(1+i)^n}{(1+i)^n-1}$

(P-S) is defined as before.

The (P-S)(CRF-i%-n) part of the total equation establishes an annual payment for the economic life of the vehicle which recovers the initial investment, P, less the portion that is recovered by the salvage value S at an acceptable rate of return, i%.

(S)(i%) the second part of the equation accounts for the annual return that would have been earned by money represented by the salvage value, S, if this money had been invested at the acceptable interest rate, i%.

Applying the equivalent capital recovery depreciation formula to our problem gives

$$\begin{aligned} CRD &= (P-S)(CRF\text{-}6\%\text{-}5)+Si\% \\ &= (15{,}000-1500)(.2374)+(1500)(6\%) \\ &= (13{,}500)(.2374)+(1500)(0.06) \\ &= 3{,}204.90 + 90 = \$3{,}294.90 \end{aligned}$$

To show that this annual charge produces an equivalent capital recovery, we can compare the present worth of capital recovery depreciation to the prior calculations.

(CRD)(SPWF-i%-n) Total present worth of series of payments

where: SPWF = series present worth factor = $\frac{(1+i)^n-1}{i(1+i)^n}$

Therefore: (CRD)(SPWF-6%-n) = (3,294.90)(4.2124)
= $13,879

The results are equivalent; therefore, the present worth of capital-recovery depreciation equals the present worth of capital recovery plus return for straight-line and sum-of-the-years'- digits depreciation. Thus, the one equation for capital-recovery depreciation can be used for comparing the time value of alternatives, regardless of the method actually employed for depreciation accounting.

Replacement Concepts

Replacement refers to a broad concept comprising the selection of similar but newer vehicle substituted and/or the evaluation of different ways to perform a vehicle's function. For example, old equipment could be replaced by newer models that operate similarly but have better performance. There are many clues or factors that lead to a replacement investigation - a vehicle becomes less efficient, operating costs increase, current demands cannot be met, new developments make older methods noncompetitive. Any one of these factors or a combination of them could lead to a decision to replace or retire vehicles.

A replacement decision is between the present vehicle, called the defender, and currently available replacement alternatives, called challengers (1).

The defender may or may not be at the end of it's economic life. The challengers may or may not perform the function of the defender in the same way. The decision environment is constrained by current operating data and estimates of future outcomes based on the latest information. Past performances and previous replacement decisions are not pertinent to the decision.

Comparisons between the defender and its challengers are made by determining the time-value of receipts and disbursements associated with each alternative. Annual cost, present worth, or rate of return methods may be used. The choice depends on the pattern of cash flow, length of the study and/or the type of operational framework, municipal, commercial, etc., within which the replacement decision is made.

Annual cost comparisons are probably the most common and will be used in this analysis because of the features of non-profit municipal operation.

The outcome of a decision cannot start before the moment a decision is made (1). Occurrences prior to the decisionmaking point are common to all the alternatives being considered. Therefore, any information available up to the moment a decision is made applies to the challenger as well as to the defender. The manager making the replacement decision should always be seeking the alternative that will provide him with the least future annual cost and still satisfy prescribed performance standards.

Replacement Analysis

The cash flow from the retention or replacement of a collection vehicle is a composite of many separate cost categories. The cost categories relevant to the replacement decision are:

- Present cost or worth of a vehicle.
- Depreciation method used and assumed length of economic life.
- Resale, salvage, or scrap value of the vehicle during its economic life.
- Operating and Maintenance Costs
  - Gasoline
  - Oil
  - Lubrication
  - Tires
  - Servicing
  - Repair
  - Overhaul
  - Amount and pattern of maintenance costs
  - Cost of waste and inefficiency
  - Inspection and modification
- Insurance
- Interest on capital

For each of the categories listed above dollar values must be determined on an annual basis. With this annual cost information one can determine the total annual cost and the equivalent uniform annual cost.

In this replacement analysis, present collection vehicles would be replaced because of physical deterioration with a similar asset. Although a replacement decision may be because of functional obsolenscence or inadequacy, these factors are not of major significance in this replacement study.

However, in a study of this type they certainly could be of major significance at a later date. Therefore, a solid waste manager must be continually abreast of his current and future operational needs and current developments in the field of solid waste collection.

To demonstrate the recommended procedure of replacement analysis for a collection vehicle, I will use two different approaches; one is slightly simpler and less accurate.

Solid Waste Collection Vehicle Replacement Analysis - Sample Problem

Given: Purchase price is $15,000. Information indicates that the sum-of-the-years'-digits depreciation method closely follows the vehicle's actual value. Past information indicates that a 5 year depreciation period is the most suitable economic life.

Resale value after 5 years is $1,500.

Inefficiency of operation (downtime), insurance costs, operating and maintenance costs which includes gasoline, oil, lubrication, tires, servicing, repairs, overhaul, modification and inspection vary on a yearly basis as follows. (Table 4).

Table 4

Vehicle's Annual Costs

Item	Year 1	2	3	4	5
Operating and Maintenance Costs	3,000	3,400	4,000	3,900	4,800
Insurance	400	400	400	400	400
Inefficiency of Operation	100	300	800	800	1100
Subtotal of Annual Costs	3,500	4,100	5,200	5,100	6,300

All items listed except inefficiency of operation can be quite easily determined in practice. Inefficiency of operation can be determined for the vehicle by charging a unit operational cost for the assigned time for a standby vehicle needed to handle the primary vehicle's assigned duties. Accounting details of this procedure will be shown in the following subsection of this report.

The City currently receives 6% on invested capital.

Determine: a) How many years should the vehicle be kept in service to minimize average annual costs if interest on unrecovered capital is not considered
b) if interest received is 6%.

Solution: a) From a previous problem on page 18 the depreciation charge for each year is as shown in Table 5 under capital costs.

The average cost per year or average annual cost is the sum of the accumulated capital costs plus operating costs divided by the number of years in the cumulative period.

From this theoretical example, the minimum average cost is obtained by keeping the collection vehicle for four years.

b) With all cost factors and information the same except the interest rate, we obtain the results as shown in Table 6.

The total annual cost of service is obtained by adding together the operating costs, the depreciation or capital cost, and the interest on the value of vehicle at the beginning of the year. The equivalent uniform annual cost of service if retired at the end of the year is determined from the annual total annual cost of service figures by first multiplying each total annual cost of service value by the appropriate single payment present worth factor at six percent

Table 5

Vehicle's Average Annual Cost with 0% Interest

Age of Vehicle, Year (1)	Operating Cost (2)	Cumulative Operating Cost (3)	Capital Cost (4)	Cumulative Capital Cost (5)	Total Cost (3)+(5) (6)	Average Annual Costs 6 ÷ 1 (7)
1	3,500	3,500	4,500	4,500	8,000	8,000
2	4,100	7,600	3,600	8,100	15,700	7,850
3	5,200	12,800	2,700	10,800	23,600	7,867
4	5,100	17,900	1,800	12,600	30,500	7,625
5	6,800	24,700	900	13,500	38,200	7,640

Table 6
Vehicle's
Equivalent Uniform Annual Costs - 6% Interest

Age of Vehicle, Year (1)	Operating Cost (2)	Capital Cost or Depreciation During Year (3)	Value at Beginning of Year (4)	Interest on Value at Beginning of Year (5)
1	3,500	4,500	15,000	900
2	4,100	3,600	10,500	630
3	5,200	2,700	6,900	414
4	5,100	1,800	4,200	252
5	6,800	900	2,400	144

Total Annual Cost of Service (2)+(3)+(5) (6)	PWF, 6% (6) (7)	PW of Cost of Service During Year (6)+(7) (8)	PW of Cost of Service Since Placed in Service (9)	CRF 6% (10)	Equivalent Uniform Annual Cost If Retired End of Year (11)
8,900	.9434	8,396	8,396	1.06	8,900
8,300	.8900	8,396	15,810	0.5454	8,623
8,314	.8396	6,980	22,790	.3741	8,526
7,152	.7921	5,665	28,455	.2886	8,212
7,844	.7473	5,862	34,317	.2374	8,147

interest to find its present worth of cost of service during the year; then calculating the present worth of cost of service since placed in service by summing the present worth of cost of service during each year up to the year in question; and finally multiplying this present value of the cost of service since placed in service by the capital-recovery factor to obtain annual equivalent cost if retired at the end of the year.

From this more detailed and more exact analysis the minimum annual cost can be obtained for the collection vehicle after a minimum period of five years. Because the analysis was limited to five years, it is impossible to tell if the minimum equivalent annual cost was reached after five years. Although in this example, minimum annual costs for a collection vehicle were obtained in different years by different methods, generally the minimum annual cost pattern would be the same; thus the average annual cost approach with zero % interest would give acceptable results the majority of the time. A theoretical replacement analysis of this type and the resulting replacement cycle is only as accurate as the assumptions and data behind it and would be valid only if the purchase price, annual operation and maintenance costs, and salvage value were repeated in the replacement vehicle.

When comparing a challenger which introduces a repeating cycle, with a present vehicle, the minimum average cost or equivalent uniform annual cost of the challenger is matched against the cost expected for the defender during the next year. If the average cost or equivalent annual cost is less a replacement is indicated.

Therefore, accurate cost data and sound analysis are essential to the solid waste manager for making competent replacement decisions.

Cost Data and Analysis in the Replacement Decision

The data collection forms recommended for use in this study have one overall objective. This objective is to translate all direct and indirect vehicle operational costs into monetary units for replacement analysis. With accurate operation and capital cost information, reliable estimates of future annual costs should be possible.

Accurate cost and analysis information properly placed on the following forms will give the Superintendent of Sanitation the necessary tools for effective collection vehicle replacement decisions.

Monthly summary of solid waste collection vehicle operational expenses (Form 1). This form can be used to record and calculate all monthly expenses for one vehicle. It should be completed on a monthly basis by the accounting department and a copy returned to the Superintendent of Sanitation for his review and analysis. The form is based on defining all operational expenses in terms of dollars and cents. The hours of downtime for this vehicle should be multiplied by a unit operational cost for a substitute vehicle and any additional labor cost required for doing the job intended for the primary vehicle. Overhead costs should include the applicable portion of management's salaries and maintenance personnel's wages, building depreciation and maintenance costs, utilities, liability and property insurance, and charges from supporting city departments where applicable.

The other cost items are recorded directly in terms of common monetary units.

Use of Form 1 will give the Superintendent of Sanitation an effective tool in analyzing vehicle operational costs and cost trends. Detailed operational cost analysis is possible by use of the equations given at the end of this form.

By using an engine hour meter on each vehicle along with accurate data, the Superintendent of Sanitation will have an effective tool in making sound replacement decisions. Although odometer readings can be used in place of engine hour readings for vehicle operational cost analysis, mileage traveled by a collection vehicle is a poor parameter for evaluating operational costs for a collection vehicle because of the nature of the vehicle's use.

Form 1 is also applicable for use in budgetary cost accounting and planning and can also be valuable to the Superintendent of Sanitation in budget preparations.

Form 1
Monthly Summary of Solid Waste Collection
Vehicle (Defender) Operational Expense

Vehicle No._____ Month_____Year_____

Date	Starting Engine Hour Meter Reading	Fuel Gals. (1)	Oil-Quarts (2)	Lubrication (3)	Tires (4)	Other Supplies (5)	Insurance (6)	Hours of down time (7)	Overhead Rate/day (8)
1									
2									
3									
4									
5									
6									
7									
8									
9									
10									
11									
12									
13									
14									
15									
16									
17									
18									
19									
20									
21									
22									
23									
24									
25									
26									
27									
28									
29									
30									
31									
Ending Engine Hour Reading									
Unit Cost (where applicable)*									
Total Cost									

Form 1 continued

Vehicle No._____ Month_____Year_____

Date	Starting Engine Hour Meter Reading	Type of repair or Service	Repair or Service Labor, Hrs, Amt,$ (9)	Repair Parts (10)	Outside Charges (11)	Other Expenses Description,Amt.$ (12)
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						
18						
19						
20						
21						
22						
23						
24						
25						
26						
27						
28						
29						
30						
31						
Ending Engine Hour Reading						
Subtotals:						
Unit Cost (where applicable)						
Total Cost						

Form 1 continued

Total Monthly Cost = Σ Columns 1 thru 12
Budgeted Monthly Cost =

Cumulative Monthly Cost =
Cumulative Budgeted Monthly Cost =
% Cumulative Change from Budgeted Cost =

Vehicle's Age =
Vehicle's Total Monthly Operational Cost Rate =

$$\frac{\Sigma \text{ Columns 1 thru 12}}{\text{Total Monthly Engine Hours}}$$

Vehicle's Direct Monthly Operational Cost Rate =

$$\frac{\Sigma \text{ Columns 1 thru 6 and 8 thru 12}}{\text{Total Monthly Engine Hours}}$$

Form 2

Annual summary and analysis of solid waste collection vehicle operational expense (Form 2). This form should be used for analyzing annual operation expenses for one vehicle. Accurate operational cost analysis is based on good vehicle operational cost data. Without good operational cost data and accurate annual budgeting, the analysis of Percent Cumulative Charge from Annual Budget is pointless. This can be used as an important tool to the solid waste manager in budget planning.

Analysis of individual vehicle costs by the Annual Operational Cost Rate is necessary for making good estimates for future annual costs of this vehicle in replacement decisions. It is recommended that annual operational costs for each vehicle be graphed as a function of time to help visualize the operational cost and to help estimate future annual operating cost.

When annual operational cost rates are used for annual replacement vehicle analysis, the defender's and challenger's total annual operational cost must be based on the same number of engine hours or other similar baseline. Only by use of a similar baseline will it be possible to make a sound replacement decision.

Form 2

Annual Summary and Analysis of Solid Waste Collection Vehicle (Defender) Operational Expense

Date of Purchase _____ Age of Vehicle_____Date_____

Truck Chassis _____ Body_____ Number_____

Month	Total Monthly Operational Cost[1] (1)	Budgeted Monthly Cost[1] (2)	Direct Monthly Operational Cost Rate[2] in $/hr. (3)
January			
February			
March			
April			
May			
June			
July			
August			
September			
October			
November			
December			

Total Annual Operational Cost = Σ Column 1

%Cumulative Change from Annual Budget:

$$\left[\frac{\Sigma(2)-\Sigma(1)}{\Sigma(2)}\right][100]$$

[2]Annual Operational Cost Rate = $\frac{\Sigma \text{Column } 3}{12}$

[1]Obtain from Form 1

[2]Transfer result to Form 5 for further analysis

Note: A positive percentage value indicates less operational cost than budgeted, while a negative value indicates an unfavorable annual operational cost trend.

Form 3

Estimated annual capital cost or depreciation schedule for new solid waste collection vehicle (Challenger) (Form 3). This form is used to account for loss in vehicle value or capital recovery with time. The same depreciation method should be used to compare a challenger and a defender, unless it is clear that the depreciation method used for the defender does not accurately account for capital recovery or the challenger will depreciate in a different manner than the defender.

Estimated Annual Capital Cost or Depreciation Schedule for New Solid Waste Collection Vehicle (Challenger)

Age of Vehicle, Year (1)	Estimated Purchase Price or Book Value at Beginning of year (2)	Estimated Capital Cost or Depreciation Charge in Year (3)	Estimated Cumulative Capital Cost (4)
1			
2			
3			
4			
5			
6			
7			

Truck chassis and model:
Compactor body and size:
Vehicle's estimated useful life:
Depreciation method used:

Form 4

Estimated average annual cost for new solid waste collection vehicle (Challenger) during useful life (Form 4.). This form is used to help the manager determine the minimum average annual cost for a new collection vehicle so that this information can be properly applied in replacement analysis (Form 5). The minimum average annual cost is the lowest yearly cost computed in column 7. This minimum yearly cost must be transferred to column 13 or Form 5 after each annual analysis. The computations leading to the average annual cost are shown by use of column numbers and arithmetic operations. The information required for Form 4 must be recomputed on an annual basis and/or at the time of replacement decision analysis.

The cost information presented in this table should reflect operating and capital costs as expected with current information and the present worth of money. If monetary inflation effects are incorporated into the average annual cost of the challenger, a true comparison between a challenger and a defender cannot be made; however, increased operating costs with time, without inflation are necessary to give an accurate cost picture of the challenger for a valid analysis.

Form 4
Estimated Average Annual Cost for New
Solid Waste Collection Vehicle (Challenger)
During Useful Life

Estimated Purchase Price _____
Estimated Useful Life, Years _____

Age of Vehicle, Years (1)	Estimated Operating Costs[1] (2)	Estimated Cumulative Operating Costs Σ(2) (3)	Estimated Capital Cost[2] (4)	Estimated Cumulative Capital Cost 2 Σ(4) (5)	Total Costs (3)+(5) (6)	Average Annual Cost (6)÷(1) (7)
1						
2						
3						
4						
5						
6						
7						

Minimum average annual cost = lowest annual cost given in column 7.

[1] Complete evaluation with Forms 1 & 2 required annually for proposed new solid waste collection vehicle. Previous annual cost data may be used with appropriate cost adjustments if vehicle is being replaced by a similar asset with similar operating features. Likewise annual operating cost data must use an equal number of annual hours for the challenger and defender to make a valid replacement decision analysis.

[2] Obtain from Form 3.

Form 5

Solid waste collection vehicle annual replacement analysis (Form 5). It is recommended that this form be completed at the end of a calendar year or at least on an annual basis so that it can be useful for preparing annual budgets, determining vehicle operational expenses and vehicle purchasing patterns. When the estimated average annual cost for the defender for next year (column 12) is greater than the estimated minimum average annual cost for the challenger during its useful life (column 13), a replacement vehicle is recommended. By using this approach the solid waste manager can make sound replacement decisions.

Form 5
Solid Waste Collection Vehicle Annual
Replacement Analysis

Defender Purchase Date_____ Year_____
Truck Chassis_____ Body_____ No._____

Year Ending Date (1)	Age of Vehicle, Years & Engine Hours (2)	Purchase Price or Value at Beginning of Year (3)	Capital Cost or Depreciation During Year (4)	Cumulative Capital Cost (5)	Previously Estimated Direct Annual Operating Cost (6)	Total Direct Annual Operating Costs[2] (7)	Estimated Direct Annual Operating Cost for Next Year (8)	Cumulative Operating Costs (9)	Total Costs (5)+(9) (10)

Age of Vehicle Years & Engine Hours	Average Annual Cost of Defender (10)÷(2) (11)	Estimated Average Annual Cost for Defender for Next Year (12)	Estimated Minimum Average Annual Cost for Challenger During Useful Life[1] (13)

[1]Obtain this information from Form 4, column 7.

[2]Total direct annual operating costs must use the same number of engine hours for the challenger also for a valid comparison.

Solid Waste Collection Vehicle Selection Methodology

Compactor Body Selection

The DARE technique as explained in Appendix A (9) is based on developing important criteria which are relatively independent to compare various alternatives. The criteria or major factors considered in this analysis for comparison of solid waste compactor bodies are:

1. The type of refuse collected
2. Collection method employed
3. Size/capacity of body
4. Safety of operation
5. Watertightness and quality of body construction
6. Ease of cleanability
7. Effective loading height
8. Speed of loading compaction cycle
9. Degree of compaction of refuse and density of refuse inside compactor
10. Capital cost
11. Operation and maintenance costs
12. Reliability or efficiency of operation
13. Ease of maintenance
14. Effective width and size of loading hopper
15. Value of compactor body as a function of time, i.e., trade-in value or salvage value
16. Cost, speed and quality of parts replacement and repair service provided by the manufacturer's dealer
17. Manufacturer's provision of current literature consisting of detailed specifications and recommended preventive maintenance procedures.
18. Manufacturer's ability to deliver complete refuse collection vehicle within 45 days from receipt of

chassis at their plant to the City of Lawrence; i.e., total delivery time from date of order to receipt by City should not exceed 90 days.

19. Flexibility for use to collect different types of refuse
20. Ease of operation by driver and collectors.

Note: The order of listing is arbitrary and has no intended significance on the relative importance of a factor.

Derivation of Factor Weights

Using the preceding criteria the author by use of a pairwise comparison procedure developed R values or quantitative ratios for determining the relative importance of each factor in comparison to the factor just below it. This began by placing a 1.0 in the K column opposite the last factor, (Table 7). Each remaining K value was formed by the product of its predecessor and the R value opposite it in a zigzag route up the table. The second last element in the K column, 0.5, results from multiplying the 1.0 below by the 0.5 to its left. This procedure is continued in a zigzag manner upward to develop the required K values. Although the K values can be used directly as factor weights, it is more convenient to convert them to sum to one. Thus, the K column values are summed to obtain 37.4. Each member of the K column is divided by this sum to obtain the W column. The results are shown in Table 7.

Table 7

Derivation of Factor Weights, W, for Application in Selection of Solid Waste Compactor Bodies

Factor		R	K	W
1.	Type of refuse collected	0.5	0.8	.02
2.	Collection method employed	1.0	1.5	.04
3.	Size/capacity of body	0.3	1.5	.04
4.	Safety of operation	5.0	5.0	.13
5.	Quality of body construction	2.0	1.0	.03
6.	Ease of cleanability	1.0	0.5	.01
7.	Effective loading height	1.0	0.5	.01
8.	Speed of loading compaction cycle	1.0	0.5	.01
9.	Density of refuse inside compactor	0.2	0.5	.01
10.	Capital Cost	0.3	2.4	.07
11.	Operation and maintenance costs	2.0	8.0	.22
12.	Reliability of operation	2.0	4.0	.11
13.	Ease of maintenance	10.0	2.0	.05
14.	Size of loading hopper	0.1	0.2	.01
15.	Salvage value as a funtion of time	0.5	2.0	.05
16.	Cost, speed and quality of parts service	4.0	4.0	.11
17.	Manufacturer's provision of pertinent literature	2.0	1.0	.03
18.	Manufacturer's ability to deliver body	1.0	0.5	.01
19.	Flexibility in refuse collection	0.5	0.5	.01
20.	Ease of operation by driver and collectors.	-	1.0	.03
			37.4	1.00

Derivation of Factor Subscores

The next phase in the use of the DARE technique is to evaluate the alternatives in terms of each of the twenty factors. As mentioned in the introduction this evaluation was limited to compactor body equipment dealers within 50 miles of Lawrence. With this limitation there were three major units to chose from - Heil, Leach and Garwood.

Using the manufacturer's equipment literature an information listing was compiled for each unit in relation to the 20 factors. Where information was lacking the Superintendent of Sanitation and his staff filled in information which they had discovered through their many years of operating and maintenance experience. This information as compiled is listed in Table 13, Appendix C.

In an attempt to take advantage of the many years of experience of the Bureau of Sanitation staff, the three alternative compactor bodies were evaluated by the Superintendent of Sanitation, the Sanitation Department Foreman, and the Sanitation Department Consultant. These three evaluations along with the authors were equally weighted in determining R values for the Derivation of Factor Subscores, S. The procedure for determining the S values is the same as used in deriving the Factor Weight, W. The results are shown in Table 8.

It should be noted that these R value determinations are based on the principle that the more desirable the alternative is, the higher the score the alternative receives.

Table 8
Derivation of Factor Subscores, S, for Application in Selection of Solid Waste Compactor Bodies

		R	K	S
1.	Type of refuse collected			
	Heil	1.0	1.0	.33
	Leach	1.0	1.0	.33
	Garwood	-	1.0	.33
			3.0	.99
2.	Collection method employed			
	Heil	1.0	1.0	.33
	Leach	1.0	1.0	.33
	Garwood	-	1.0	.33
			3.0	.99
3.	Size/capacity of body			
	Heil	1.0	1.0	.33
	Leach	1.0	1.0	.33
	Garwood	-	1.0	.33
			3.0	.99
4.	Safety of operation			
	Heil	0.9	0.99	.32
	Leach	1.1	1.1	.36
	Garwood	-	1.0	.32
			3.09	1.00
5.	Quality of body construction			
	Heil	0.7	1.05	.30
	Leach	1.5	1.50	.42
	Garwood	-	1.00	.28
			3.55	1.00
6.	Ease of cleanibility			
	Heil	0.9	1.17	.34
	Leach	1.3	1.3	.37
	Garwood	-	1.00	.29
			3.47	1.00

7. Effective loading height	R	K	S
Heil	1.0	1.0	.33
Leach	1.0	1.0	.33
Carwood	-	1.0	.33
		3.0	.99

8. Speed of loading compaction cycle			
Heil	1.1	.99	.34
Leach	.9	0.90	.31
Garwood	-	1.0	.35
		2.89	1.00

9. Density of refuse inside compactor			
Heil	1.0	1.0	.33
Leach	1.0	1.0	.33
Garwood	-	1.0	.33
		3.0	.99

10. Capital Cost (list price)			
Heil	1.03	0.97	.33
Leach	0.94	0.94	.32
Garwood	-	1.0	.35
		2.91	1.00

11. Operation and maintenance costs:

Not enough information available.

12. Reliability of operation:

No information available

13. Ease of maintenance			
Heil	0.5	.70	.23
Leach	1.4	1.40	.45
Garwood	-	1.00	.32
		3.10	1.00

14. Size of loading hopper			
Heil	1.0	1.4	.37
Leach	1.4	1.4	.37
Garwood	-	1.0	.26
		3.8	1.00

		R	K	S
15.	Salvage value as a function of time:			
	No information available.			
16.	Cost, speed, and quality of parts service:			
	No information available			
17.	Manufacturer's provision of pertinent literature:			
	Not enough information available.			
18.	Manufacturer's ability to deliver body:			
	Not enough information available			
19.	Flexibility in refuse collection			
	Heil	0.8	1.36	.33
	Leach	1.7	1.7	.42
	Garwood	-	1.0	.25
			4.06	1.00
20.	Ease of operation by drivers and collectors			
	Heil	1.1	1.21	.37
	Leach	1.1	1.1	.33
	Garwood	-	1.0	.30
			3.31	1.00

Derivation of Alternative Scores

The final step in the procedure is to determine the Alternatives Scores, A. This is accomplished by summing the cross-products of the factor weights and factor subscores to produce the final scores for each of the alternatives. The results are tabulated in Table 9.

Table 9
Derivation of Alternatives Scores, A, for Selecting Compactor Bodies

Factor	Factor Weights	Heil		Leach		Garwood	
		Factor Subscores	Weighted Scores	Factor Subscores	Weighted Scores	Factor Subscores	Weighted Scores
1. Type of refuse collected.	0.02	0.33	0.0066	0.33	0.0066	0.33	0.0066
2. Collection method employed.	0.04	0.33	0.0132	0.33	0.0132	0.33	0.0132
3. Size of body.	0.04	0.33	0.0132	0.33	0.0132	0.33	0.0132
4. Safety of operation.	0.13	0.32	0.0416	0.36	0.0468	0.32	0.0416
5. Quality of body construction.	0.03	0.30	0.0090	0.42	0.0126	0.28	0.0084
6. Ease of cleanability.	0.01	0.34	0.0034	0.37	0.0037	0.29	0.0029
7. Effective loading height.	0.01	0.33	0.0033	0.33	0.0033	0.33	0.0033
8. Speed of loading compaction cycle.	0.01	0.34	0.0034	0.31	0.0031	0.35	0.0035

Table 9 continued

Factor	Factor Weights	Heil Factor Subscores	Heil Weighted Scores	Leach Factor Subscores	Leach Weighted Scores	Garwood Factor Subscores	Garwood Weighted Scores
9. Density of refuse inside compactor.	0.01	0.33	0.0033	0.33	0.0033	0.33	0.0033
10. Capital Cost.	0.07	0.33	0.0231	0.32	0.0224	0.35	0.0245
11. Operation and maintenance costs.	0.22	Not enough information available. (NEIA)	-	NEIA	-	NEIA	-
12. Reliability of operation.	0.11	No information available (NIA)	-	NIA	-	NIA	-
13. Ease of maintenance.	0.05	0.23	0.0115	0.45	0.0225	0.32	0.0160
14. Size of loading hopper,	0.01	0.37	0.0037	0.37	0.0037	0.26	0.0026
15. Salvage value as a function of time.	0.05	NIA	-	NIA	-	NIA	
16. Cost, speed and quality of parts service.	0.11	NIA	-	NIA	-	NIA	-

Table 9 continued

Factor	Factor Weights	Heil Factor Subscores	Heil Weighted Scores	Leach Factor Subscores	Leach Weighted Scores	Garwood Factor Subscores	Garwood Weighted Scores
17. Manufacturer's provision of pertinent literature.	0.03	NEIA	-	NEIA	-	NEIA	-
18. Manufacturer's ability to deliver body.	0.01	NEIA	-	NEIA	-	NEIA	-
19. Flexibility in refuse collection.	0.01	0.32	0.0033	0.42	0.0042	0.25	0.0025
20. Ease of operation by drivers and collectors.	0.03	0.37	0.0111	0.33	0.0099	0.30	0.0090
Totals			.1497		0.1685		0.1506

Vehicle Chassis Selection

In applying the DARE technique (9) to different vehicle chassis the same procedures were used. First the criteria or major factors for comparison were developed. They are:

1. The type of refuse collected and/or weight hauling capacity of chassis.
2. Type of collection method employed (directly related to type of compactor body chosen)
3. Width and condition of streets and alleys, i.e. ease of manuverability and size.
4. Length of haul to disposal site.
5. Cost, speed and quality of parts replacement and major repair service provided by the manufacturer's dealer.
6. Safety of operation.
7. Overall vehicle performance and reliability.
8. Capital cost.
9. Operation and maintenance costs.
10. Ease of serviceability.
11. Value of vehicle chassis as a function of time, i.e., trade in value or salvage value.
12. Manufacturer's provision of current literature for truck chassis; literature should consist of detailed specifications and recommended preventive maintenance procedures.
13. Manufacturer's ability to deliver chassis to refuse body manufacturer's plant within 45 days from time of order.
14. Ease of operation by drivers and collectors.

Note: The order of listing is arbitrary and has no intended significance on the relative importance of a factor.

Derivation of Factor Weights

Next factor weights were developed through the use of pairwise comparisons. The results are listed in Table 10 below.

Table 10
Derivation of Factors Weights, W, for Application in Selection of Solid Waste Collection Vehicle Chassis

Factor	R	K	W
Weight hauling capacity of chassis	1.4	2.5	.04
Type of collection method employed	1.0	1.8	.03
Ease of maneuverability and size	1.0	1.8	.03
Length of haul to disposal site	0.2	1.8	.03
Cost, speed and quality of parts service	1.0	9.0	.17
Safety of operation	1.0	9.0	.17
Overall vehicle performance and reliability	3.0	9.0	.17
Capital cost	0.3	3.0	.06
Operation and maintenance costs	5.0	10.0	.18
Ease of serviceability	1.0	2.0	.14
Salvage value as a function of time	2.5	2.0	.04
Manufacturer's provision of pertinent literature	2.0	0.8	.01
Manufacturer's ability to deliver chassis	0.4	0.4	.01
Ease of operation by driver and collectors	-	1.0	.02
		54.1	1.00

Derivation of Factor Subscores

Originally four different truck chassis were to be evaluated. They were: 1) Ford C series tilt cab, 2) Ford Louisville series short conventional, 3) GMC TE-6500 series tilt cab, and 4) International Cargostar CO-1810A series tilt cab. Because of the lack of information and their similarity the two Ford trucks were grouped into one category. Using these three alternatives R values were developed for deriving the factor subscores on the basis of manufacturer's equipment literature and the Sanitation Department staff experience. The information used for this evaluation is listed in Table 14, Appendix C.

The results from this evaluation is listed in Table 11. Factor subscores, S, for a given factor usually add to one, except when all three units are equal in performance. Each unit is assigned to 0.33 for equality and the extra 0.01 in the total is lost due to rounding off of the S values to two significant figures.

Table 11

Derivation of Factor Subscores, S, for Application in Selection of Solid Waste Collection Vehicle Chassis

		R	K	S
1.	Weight hauling capacity of chassis			
	Ford	1.0	1.0	0.33
	GMC	1.0	1.0	0.33
	Internnational	-	1.0	0.33
				0.99
2.	Type of collection method employed			
	Ford	1.0	1.0	0.33
	GMC	1.0	1.0	0.33
	International	-	1.0	0.33
				0.99
3.	Ease of manuverability and size			
	Ford	1.0	1.0	0.33
	GMC	1.0	1.0	0.33
	International	-	1.0	0.33
				0.99
4.	Length of haul to disposal site			
	Ford	1.0	1.0	0.33
	GMC	1.0	1.0	0.33
	International	-	1.0	0.33
				0.99
5.	Cost, speed, and quality of parts service			
	Ford	1.9	2.09	0.50
	GMC	1.1	1.1	.26
	International	-	1.0	.24
				1.00
6.	Safety of operation			
	Ford	1.0	1.0	0.33
	GMC	1.0	1.0	0.33
	International	-	1.0	0.33
				0.99
7.	Overall vehicle performance and reliability			
	Ford	1.0	1.0	0.33
	GMC	1.0	1.0	0.33
	International	-	1.0	0.33
				0.99

		R	K	S
8. Capital cost (list price range)				
	Ford	1.0	1.0	0.33
	GMC	1.0	1.0	0.33
	International	-	1.0	0.33
				0.99

9. Operation and maintenance costs:

No information available.

10. Ease of serviceability

Ford	1.2	1.2	.38
GMC	1.0	1.0	.31
International	-	1.0	.31
		3.2	1.00

11. Salvage value as a function of time:

No information available.

12. Manufacturer's provision of pertinent literature:

No information available.

13. Manufacturer's ability to deliver chassis:

No information available.

14. Ease of operation by driver and collectors:

Ford	1.1	1.1	.36
GMC	1.0	1.0	.32
International	-	1.0	.32
		3.1	1.00

Derivation of Alternatives Scores

The alternative scores, A, were derived as before with the most desirable alternative receiving the highest score. The alternative scores and the total score for each alternative is given in table 12.

Table 12

Derivation of Alternative Scores, A, for Selecting Solid Waste Vehicle Chassis

Factors	Factor Weights	FORD Factor Subscores	FORD Weighted Scores	GMC Factor Subscores	GMC Weighted Scores	INTERNATIONAL Factor Subscores	INTERNATIONAL Weighted Scores
1. Weight hauling capacity of chassis	0.04	0.33	0.0132	0.33	0.0132	0.33	0.0132
2. Type of collection method employed	0.03	0.33	0.0099	0.33	0.0099	0.33	0.0099
3. Ease of manuverability and size	0.03	0.33	0.0099	0.33	0.0099	0.33	0.0099
4. Length of haul to disposal site	0.03	0.33	0.0099	0.33	0.0099	0.33	0.0099
5. Cost, speed and quality of parts service	0.17	0.50	0.0850	0.26	0.0442	0.24	0.0408
6. Safety of operation	0.17	0.33	0.0561	0.33	0.0561	0.33	0.0561
7. Overall vehicle performance and reliability	0.17	0.33	0.0561	0.33	0.0561	0.33	0.0561
8. Capital cost (list price range)	0.06	0.33	0.0198	0.33	0.0198	0.33	0.0198
9. Operation and maintenance costs	0.18	No information available (NIA)				NIA	

Table 12 continued -

Factors	Factor Weights	FORD Factor Subscores	FORD Weighted Scores	GMC Factor Subscores	GMC Weighted Scores	INTERNATIONAL Factor Subscores	INTERNATIONAL Weighted Scores
10. Ease of serviceability	0.04	0.38	0.0152	0.31	0.0124	0.31	0.0124
11. Salvage value as a function of time	0.04	NIA	-	NIA	-	NIA	-
12. Manifacturer's provision of pertinent literature	0.01	NIA	-	NIA	-	NIA	-
13. Manufacturer's ability to deliver chassis	0.01	NIA	-	NIA	-	NIA	-
14. Ease of operation by drivers and collectors	0.02	0.36	0.0072	0.32	0.0064	0.32	0.0064
			0.2823		0.2379		0.2345

Recommended Compactor Body and Vehicle Chassis

Upon review of Table 9 and Table 12 it is readily apparent that the highest total score for the compactor unit was obtained by Leach and the highest total score for the truck chassis was obtained by the Ford Louisville series short conventional.

The compactor body analysis gave Leach the victory by a limited margin, however, yet strong enough to indicate that Leach probably makes the best rear loading compactor available in the vicinity of Lawrence, Kansas. The word "probably" has been used because from Table 9 it is clear that for six items (four key ones) which represent 53 percent of the decisionmaking weight only limited or no information was available. The major weight of these items was related directly or indirectly to operation and maintenance costs. Since manufacturer's literature is wholly inadequate to meet the evaluation criteria, it may be worth obtaining the data necessary to help in compactor body selection. Yet with good data of this type, the choice may still be the same. However, from the standpoint of vehicle chassis and compactor body replacement, good data on operating and maintenance costs is essential. Without this data only intuition can be used in the replacement decisionmaking process. The truck chassis analysis in Table 13 indicated that the Ford Louisville series was the best choice by a reasonable margin; yet for the key item of operation and maintenance costs, which represents 18 percent of the decisionmaking weight, no information was available. For sound replacement decision, good operating and maintenance data is essential, but this information is not necessarily as critical in vehicle selection with the DARE technique although desirable.

Finally, when the City does have the capital available, and the Superintendent of Sanitation sees need for replacing old collection vehicles, very serious consideration should be given to replacing the old vehicles with the Ford Louisville series short conventional and Leach compactor combination.

Summary and Conclusions

Almost all major decisions made by a solid waste manager have economic implications. Even in the City of Lawrence which has a school term population of only 50,000, the annual budget for the Sanitation Department approaches $500,000. Therefore, sound economic decisions are essential.

The Superintendent of Sanitation must employ his judgment by use of data and analytical analysis or data and intuition or just plain intuition. Whether a decision is made by analytical analysis or intuition, good data increases the probability that it will be a better decision. Better decisions when implemented mean greater economic benefits and greater efficiency, which is the goal of competent management.

Because of the major economic investment in equipment, a sound equipment replacement policy is necessary for the Sanitation Department. A sound equipment replacement policy implies an effective maintenance program. And a competent solid waste system manager has both because he knows they are essential for keeping equipment and operating and manpower costs to a minimum.

The objectives of this study as stated in the introduction was to move toward the goal of optimum solid waste vehicle selection and replacement. Because cost data was not available for individual solid waste collection vehicles, replacement analysis was discussed through a sample problem. However, the enclosed cost accounting forms are presented along with recommended equations for replacement analysis. Data properly collected and organized is the first step; analysis of this data is the next phase. The final step is implementation of the analysis results. Implementation of the results may not always be possible at the time because of yearly budgetary constraints. However, good data and

and proper analysis are necessary for minimizing cost even though the analysis may indicate that costs could be lower if one vehicle in the collection fleet would be replaced.

The DARE technique, which is a quantitative ratio scale rating method, was used to aid in selecting the best available compactor body and best available truck chassis. Information available from manufacturer's equipment literature was inadequate to satisfy the evaluation criteria used. In evaluating compactor bodies 53 percent of the decision weight criteria were so lacking in information that no numerical values could be applied. With the truck chassis, information for 24 percent of the decision weight criteria was lacking. For both evaluations operating and maintenance costs data would have increased the author's confidence in the outcomes; however, the outcomes probably would not have changed.

From this study the author recommends that the DARE technique should be applied by one person who has all available information at his disposal. Averaging of R values for determining factor weights developed by four persons as was tried in this study is not recommended. An averaging of R values should only be considered if all persons involved have used the technique extensively.

Using the average result from two, three or four persons in developing factor subscores for the various alternatives is feasible if a thorough discussion defining the range limits which the R values will take on is considered prior to the actual independent R values determinations.

It is recommended that the Sanitation Department began immediately to collect accurate cost data in a manner as outlined by the forms in this report. This data, when so organized, will give the Superintendent of Sanitation guidance for making better decisions, thus improved economic and equipment operational efficiency.

It is also recommended that the Sanitation Department consider the purchase of Ford Louisville LN-750 series short conventional truck chassis in combination with Leach compactor bodies when old collection vehicles need to be replaced. This unit is recommended because this combination presently appears to be the best available.

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APPENDICES

Let DARE make your solid-waste decisions

Engineers discover a new method of decision making and apply it to the solid-waste problem

By **Albert J. Klee**

Evaluating the alternative solutions to solid-waste problems is a complicated task. It is often difficult to determine:

- the factors used to evaluate these alternatives,
- the evaluator's view of the importance of the factors,
- the worth of each alternative with respect to each factor.

To introduce a rational, orderly process to score alternatives, we found it necessary to examine the entire category of decision-weighing models. As a consequence, we developed a helpful new technique that produces meaningful scores, is simple to use, and which minimizes the number of decisions required of the decision-maker. This technique is DARE, an acronym for Decision Alternative Ration Evaluation.

Mr. Klee of the Bureau of Solid Waste Management was instrumental in developing the DARE technique. This bureau is a function of the U.S. Department of Health, Education and Welfare in Washington, D.C.

To explain how it works we must first review the concepts of scoring models and their use. Let us assume that there are three proposals for the disposal of municipal solid wastes: sanitary landfill, composting and incineration. Suppose that the factors (which are simply decision criteria) that will help evaluate these alternatives are:

1. Capital cost of the facility,
2. Ability of the process to salvage certain of the wastes,
3. Time needed to develop the process,
4. Contribution to air pollution of the process,
5. Operating cost of the facility.

Simple scores

One simple evaluation technique would be to consider one alternative and to assign a subscore to it for every factor selected. The sum of these subscores could constitute a "score" for the alternative, repeating the practice until all alternatives have been scored. Algebraically, the model would look like this:

$$A = S_1 + S_2 + S_3 + S_4 + S_5$$

where A is the score of the alternative being evaluated and the S values (known as "factor subscores") are the subscores assigned to this alternative for each of the five factors used to make the evaluation. However, factors are rarely of equal importance. In this example, for instance, an evaluator may feel that the air-pollution factor is of far greater importance than the salvage-value factor. Accordingly, he is able to construct a better model, one which weights each of the subscores:

$$A = S_1W_1 + S_2W_2 + S_3W_3 + S_4W_4 + S_5W_5$$

where the W-values (known as "factor weights") are numbers reflecting the relative importance of the factors used in the evaluation process. This model is a simple linear, additive one. It is satisfactory provided the factors are independent of each other (that they do not constitute optional means of satisfying the same objectives). For example, assume that one of the objectives of the disposal project is to provide a means for returning the metals in the waste to the economy as a useful by-product, and that two criteria (factors) are established. One is the feasibility of salvaging

This paper proposes a new method of decision making as an offspring of the complicated problems encountered in solid waste research. It is applicable however, to any field where one must evaluate complicated sets of competing alternatives. This new method, DARE, produces cardinally weighted scores, is simple to use, and minimizes the number of decisions required of the decision-maker. The conclusions reached in the example given in this article are for illustration only and should not be applie' to specific situations without considering local conditions.

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metals in the form of pellets, and the second is the feasibility of salvaging metals in the form of irregular pieces.

These criteria are *not* independent with regard to utility; either will satisfy the same objective. In this example, the decision-maker might well have considered the dollar value of the metal returned to the economy as well as the tonnage of the metal so returned as basic criteria.

Little dependence

These criteria, of course, constitute different means of satisfying the stated objective. The remaining discussion (and the DARE technique) assume that the decision-

maker has selected and refined his decision on criteria in such a way as to minimize dependence among them.

Now we must determine both the factor weights, W, and factor subscores, S. One method, termed "rating" assigns numbers on an arbitrary scale directly. For example, with regard to the factor weights in our problem we might, after a great deal of pondering, assign a weight of 10 to capital cost, 5 to salvage, 50 to air pollution, and so on. In addition to its somewhat arbitrary flavor, this method poses great difficulties to the decision-maker. It does have one distinct advantage, however, the factors produced are cardinal ones and we are able to determine almost at a glance just *how much more important* one factor is than any other.

An easier way

We could instead adopt a procedure which places much less strain on the decision-maker, simply ordering ("ranking") the items under consideration. With regard to factor subscores, for example, in the case of the capital-cost factor we might rank landfilling as the least expensive, incineration the next cheapest, and composting the most expensive alternative. Ranking, however, suffers from a serious drawback. It permits no indication of the *size* of a difference, as does rating.

If the number of items to be ranked or ordered is large, however, even this task might prove formidable for the evaluator. Consequently, a third procedure in which evaluators pair up and compare alternatives has attracted some interest. In value engineering, this technique is termed "forced decisions".

Evaluators then decide which item of each pair is more important or which scores higher. The "winner" receives a score of 1 (a "positive" decision), the loser a 0. For example, in comparing capital cost to salvage possibilities, we might consider capital cost more important. Capital cost scores 1 on this comparison, and salvage scores 0. Next, capital cost is compared with the air-pollution factor. If air pollution is more important, it scores 1. The total number of positive decisions for each factor then determines factor weights. A similar method derives factor subscores.

Mathematics can prove that the pairwise comparison procedure simply produces a rank ordering, although it appears at first glance to be a cardinal procedure. However, the method has the advantage that the decisions required of the decision-maker are simple. He need

compare at any one step just two items. With rating or ranking he might be confronted with dozens or even hundreds of items at one time. However, the pairwise-decision technique suffers from the fact that evaluators must make a tremendous number of comparisons when many factors are involved. For example, if a problem involved ten alternatives evaluated on the basis of 20 factors, the evaluator must make 1,090 comparisons, and each comparison requires a decision upon the part of the evaluator. Clearly, this asks too much of the decision maker.

Studies assessing the evaluation procedures described have found evaluators, for example, to consider ranking the easiest to use and rating among the hardest. Although most assume that pairwise-comparison techniques could be found highly

acceptable, they were judged to be equally as difficult as rating, primarily because of the large number of comparisons usually necessitated by the technique. Oddly enough, no significant differences appeared in the scores produced by these methods when applied to the same problems. However, if the evaluators were knowledgeable about the systems they were evaluating, they tended to *believe* that ranking systems were less reliable than rating systems for recording their judgments in spite of the fact that the improvement in reliability is more apparent than real. The psychological needs of the decision-maker, nonetheless, cannot be ignored. In experiments involving pairwise comparisons, for example, we found that subjects balked at awarding a simple 1 and 0 when the items were almost equally matched.

Our new method, DARE, draws from the strengths of these methods and minimizes their weaknesses. It is simple to use, cardinal in

Table I

Sample Problem: Derivation of Factor Weights, W

Factor	R	K	W
Capital cost	2.0	0.66	0.10
Salvage	0.1	0.33	0.05
Air pollution	2.5	3.25	0.50
Development time	1.3	1.3	0.20
Operating cost	—	1.0	0.15
		6.54	1.00

nature and, although based upon a pairwise-comparison concept, it drastically restricts the total number of comparisons necessary. To illustrate the technique, we'll apply it to the waste-disposal problem. First we list the factors in arbitrary order (more about this later) as shown in Table I. Of the three columns of numbers in this table, only the first reflects input by the evaluator. Simple calculations yield the balance.

The numbers in the R-column are quantitative ratios, assigned by the evaluator, reflecting a comparison of each factor with the one listed immediately below it. The evaluator considers air pollution to be 2½ times as important as development time, the salvage factor only one-tenth as important as air pollution, and development time 1.3 times as important as operating cost. Since the pairs are made sequentially moving down the list one factor at a time, the evaluator need make only a small number of paired comparisons, merely one less than the number of factors.

The remainder of the calculation proceeds quickly. A 1.0 always goes into the K-column opposite the last factor. Each remaining K-value is formed by the product of its predecessor and the R-value opposite it in a zigzag route up the table. The second-last element, in the K-column, 1.3, results from multiplying the 1.0 below it by the 1.3 to its left. The preceding K-column element, 3.25 is obtained by multiplying the 1.3 below it by the 2.5 to its left. Although we could use these K-values as our factor weights directly, it is more useful to convert them to sum to one. Accordingly, we add the K-column values, obtaining 6.54, and divide each member of the K-column by this sum to obtain the W column.

Table II

Sample Problem: Derivation of Factor Subscores, S

	R	K	S
1. Capital cost			
Sanitary landfill	2.5	1.25	0.46
Incinerator	0.5	0.5	0.18
Compost plant	—	1.0	0.36
		2.75	1.00
2. Salvage			
Sanitary landfill	0.5	0.5	0.20
Incinerator	1.0	1.0	0.40
Compost plant	—	1.0	0.40
		2.5	1.00
3. Air pollution			
Sanitary landfill	2.00	1.00	0.40
Incinerator	0.50	0.50	0.20
Compost plant	—	1.00	0.40
		2.50	1.00
4. Development time			
Sanitary landfill	4.0	2.4	0.60
Incinerator	0.6	0.6	0.15
Compost plant	—	1.0	0.25
		4.0	1.00
5. Operating cost			
Sanitary landfill	2.0	1.4	0.45
Incinerator	0.7	0.7	0.23
Compost plant	—	1.0	0.32
		3.1	1.00

Factor subscores

Next, we evaluate the alternatives in terms of each of the five factors by a perfectly analogous procedure to obtain the factor subscores shown in Table II. The capital cost for landfilling is 2½ times *smaller* than for incineration. Note that, since the higher the score an alternative receives the more desirable the alternative, the ratios for items such as costs and development time are really inverses of the estimated cost and time ratios. The order of listing for the factors must follow that used in Table I. The order of listing the alternatives is arbitrary, except that once determined for the first factor, we must follow it for all the remaining factors.

The final step consists of summing the cross-products of the factor weights and factor subscores to produce the final scores for each of the alternatives. We construct Table III to accomplish this conveniently. The factor weights from Table I form the first column. Then, corresponding factor subscores from Table II go under their appropriate headings. Multiplying the elements

Table III

Sample Problem: Derivation of Alternatives Scores, A

Factors	Factor weights	Sanitary Landfill Factor subscores	Sanitary Landfill Weighted scores	Incinerator Factor subscores	Incinerator Weighted scores	Compost Plant Factor subscores	Compost Plant Weighted scores
1. Capital cost	0.10	0.46	0.0460	0.18	0.0180	0.36	0.0360
2. Salvage	0.05	0.20	0.0100	0.40	0.0200	0.40	0.0200
3. Air pollution	0.50	0.40	0.2000	0.20	0.1000	0.40	0.2000
4. Development time	0.20	0.60	0.1200	0.15	0.0300	0.25	0.0500
5. Operating cost	0.15	0.45	0.0675	0.23	0.0345	0.32	0.0480
	Total Scores		0.4435	—	0.2025	—	0.3540

of the factor-subscore columns by the elements of the factor-weight column and then summing the products, produces the final total scores shown indicating that the sanitary-landfill alternative constitutes the best of the three, about one-fourth better than the runner-up, composting.

Because DARE depends upon a pairwise-comparison concept, the individual decisions which it incorporates are relatively easy to make. The decision-maker simply compares one item with another.

Reverse comparison

Should the decision-maker find it difficult to determine relative weights less than 1, he could reverse the comparison to arrive at weights such as "3-1 better," "20% better" (i.e., 1.2:1) and so on, remembering only to enter the reciprocal of such reversed relative weights in the R-value columns.

Although the order of listing the factors or alternatives in the tables is arbitrary (except where noted), this assumes that the decision-maker is consistent in his judgments (e.g., if A is 2 times as important as B and if B is 3 times as important as C; then to be consistent, A must be 6 times as important as C).

Experience with the technique, however, suggests that consistency in determining of factor weights improves when the evaluator employs a rough pre-ordering of factors.

A check on consistency can then be obtained by repeating the analysis and rearranging the factors in a random manner to effect a different order.

Occasionally, a factor may be irrelevant with regard to a particular alternative. Since, obviously, the alternative should receive a zero subscore with regard to such a factor, the most convenient procedure is to assign a subscore of zero to the alternative for this factor, and then proceed to determine the subscores for the other

alternatives as if that alternative did not exist.

From data to decision

DARE incorporates both qualitative and quantitative factors. Although the presence of the former increases the subjectivity of the final score, the fact that relative weights serve as inputs to the model insures that the decision-maker's view of the system is clearly and unequivocably stated. Should quantitative data be available, they are easily incorporated in the form of ratios which automatically produce the required relative weights.

Most scoring models permit the utilization of the consensus of the knowledge and judgment of more than one decision-maker. DARE is no exception.

However, it is also useful to compare the results produced by individual decision-makers applying the technique independently, so that it can serve as the basis for a sensitivity analysis concerning the concordance of the decision makers.

Some shortcomings

DARE is basically a technique for cardinally ordering alternatives on the basis of stated criteria. Observers can clearly determine what factors were used in such an evaluation, what the evaluator thought of the importance of these factors, and how each alternative scored. It has some shortcomings, however.

Although it determines the "best" alternative, it does not shed any light on the risk, profitability or utility of this alternative. It is clear that the decision-maker may decline to implement the best of a set of poor alternatives.

The decision to implement or not to implement rests upon other aspects of decision theory. Evaluators who know both the shortcomings and strong points of DARE, however, can employ it to great advantage. ◄◄

APPENDIX B

General Guidelines for Writing Solid Waste Collection Vehicle Chassis Specifications

1.	Make and Model:	Specify make and chassis model.
2.	GVW Rating:	a) Specify GVW rating in pounds when equipped with required size recommended tires. b) Specify the type of service, i.e., heavy duty, and that vehicle must comply with manufacturers printed literature corresponding to the maximum GVW rating.
3.	Engine:	a) Specify minimum gross horsepower, type of engine, i.e., gasoline/diesel and number of cylinders and angle of motion, i.e. b) Specify the minimum piston displacement in cubic inches.
4.	Transmission:	a) Specify type wanted, gear ratios wanted and number of forward speeds.
5.	Clutch:	Specify type and size (applicable only to standard transmission).
6.	Rear Axle:	Specify type, gear ratios and minimum capacity.
7.	Front Axle:	Specify minimum capacity.
8.	Springs:	Specify "minimum or required by stated GVW" or minimum capacity required for both front and rear axles.
9.	Brakes:	Specify a given type and auxiliary system and specify a minimum brake lining area and auxiliary system components.
10.	Tires:	Specify size, rating, type, line and "Single fronts and dual rears, etc."
11.	Wheels:	Specify type, i.e., cast spoke, 10 stud BUDD disc.
12.	Cab:	Specify type, i.e., tilt cab or short conventional.

13.	Color:	Specify color and quality of paint.
14.	Wheelbase:	Specify cab to rear axle wheelbase required for mounting compactor body and wheelbase for tilt cab or equivalent.
15.	Gas Tank:	Specify type, i.e., single or dual, side mounted on single, and capacity.
16.	Body requirement:	Specify type, and size of body to be placed on the vehicle chassis.
17.	Frame:	Specify type, shape, section modulus, and how front tow hooks should be fastened, i.e., to"longitudinal member."
18.	Steering:	Specify type, i.e. "hydraulic power steering."
19	Extra Equipment:	Specify the following:

Spare wheel and tire.

Alternator rating, i.e. minimum of 55 amp.

Type of heater and defroster.

Instrument gauges for engine operation.

Cab marker lights.

Type of side mirrors; i.e., West Coast.

Directional signals.

Seat belts.

Emergency flasher switch and signals.

Tachometer (optional with standard transmission).

Type of hand brake.

Type of windshield wipers and washers.

Type of seat covering and trim.

Vacuum reserve brake tank with gauge and light.

Engine hour meter.

20.	General:	"Equipment other than new and current-year models will not be considered as responsive to these specifications."
21.	Warranty:	"The equipment furnished under these specifications is to carry the standard warranty which is offered to the general public."
22.	Descriptive Literature:	"The bidder or quoter shall attach hereto and it shall be made a part of this bid or quotation, regularly printed, descriptive literature and detailed specification and recommended maintenance procedures as published by the factory, which corresponds with the equipment he proposes to furnish."
23.	Delivery Method:	Specify how the equipment covered in this proposal is to be delivered to refuse collection body manufacturer's factory for body mounting and the subsequent method of delivery of refuse collection vehicle to the City of Lawrence.

Under extra equipment is listed an engine hour meter. The author feels that since solid waste collection vehicles spend the majority of their time in the collection phase of use, accurate and effective cost accounting and cost data analysis is not possible through use of the common standard equipment item, the odometer. The engine hour meter may be available directly through the truck manufacturers; however, if it is not, it should be installed by a local company before the City of Lawrence begins use of the vehicle.

In determining the required chassis for mating with a compactor body, the body manufacturer should make available to the City of Lawrence the proper weight distribution to the front and rear axles for the intended truck chassis or define the compactor body's center of gravity so the distribution could be made by the City staff or truck manufacturers technical sales personnel. With the weight distribution information available

from the truck manufacturers on the truck chassis, the compactor body weight distribution, rated compactor body capacity and the estimated compacted unit solid waste density, the proper axles and gross vehicle weight ratings for the truck chassis can be determined.

Table 13
Information and Specifications Pertinent to Individual Manufacturer's Units for Application of the DARE Technique to Compactor Body Analysis*

Factor	Heil - 20 yd^3	Leach - 20 yd^3	Garwood - 20 yd^3
Type of refuse collected	Residential	Residential	Residential
Collection method employed	Collection method may be either curb, alley, backyard or set-out and set-back service. Since all units are rear loaders they are all similar and equal for this factor.		
Size/ capacity of body	20 yd^3	20 yd^3	20 yd^3
	All three units were chosen to be of the same rated capacity for equivalence and fairness in this comparison.[1]		
Safety of operation	Packing action requires that the loading hopper raise above the normal loading level before the packer plate moves down. The packing cycle may be stopped instantly with one of three buttons.	Packing cycle controlled by one lever.	Packing cycle is controlled by one lever. A second lever is used for independent operation of the packing panel. Either lever instantly stops the packing cycle.
	A safety door is available at extra cost for all units; however, is generally not used because of inconvenience and questionable safety value.[1]		
Quality of body construction.	All units have watertight bodies and hoppers.		
	Weight = 9700 lb	Weight = 10,483 lb	Weight = 9,700 lb
a. Body steel thickness	Floor = 10 ga Hi.Ten. Sides = 11 ga " " Top = 11 ga " " 10 ga = 0.1345 in. 11 ga = 0.1196 in.	Floor = 1/4 in. 3 ga Sides = 11 ga Top = 11 ga 3 ga = 0.22391 in. 11 ga = 0.1196 in.	Floor = 7 ga Hi. Ten. Sides = 11 ga. Top = 11 ga 7 ga = 0.1793 in. 11 ga = 0.1196 in.
	Body paint is air dried DuPont Delux enamel.	Body paint is baked at 200°F, high gloss enamel.	Body paint - no information available, but is probably air dried enamel.
Ease of Cleanability	Exterior cleaning is the same for all units.[1]		
	Interior cleaning is equivalent to Garwood, but more difficult than Leach.[1]	Interior cleaning is easier than Heil or Garwood.[1]	Interior cleaning is equivalent to Heil in difficulty, but not as easy as Leach.[1]

*From current literature on refuse collection units of Heil Company, Elgin Leach Corporation and Garwood Industries, Inc. (13,14,15).

Factor	Heil	Leach	Garwood
Effective loading height	31 in.	31 in.	31 in.
Speed of loading compaction cycle	12 - 14 sec.	28-32 sec., 14-16 sec. behind packing plate.[1]	10 sec., 4 sec. behind packing plate.
Density of refuse inside compactor	[2]*N.A. - employs double compaction plate.	[2]*N.A. - employs double compaction plate.	[2]*N.A. - employs double compaction plate.
Capital cost (list price)	List price for 20 yd^3 body excluding Federal excise taxes (8%), safety door, and mounting and transportation charges.		
	$7,362	$7,573	$7,130
a. Cost with safety door	$7,562	$7,623	$7,280
Operation and maintenance costs	N.A.	N.A.	N.A.
Reliability of operation	N.A.	N.A.	N.A.
Ease of maintenance	N.A. probably most difficult to maintain because of vast amount of electrical wires and switches.[1]	N.A. experience with City of Lawrence indicates the Leach unit is considerably easier to maintain than Garwood.[1]	N.A.
Size of loading hopper	1 1/2 yd^3 and 80 in. wide	1 1/4 yd^3 and 77 in. wide	1 1/2 yd^3
a. Useable hopper capacity	Approximately equal to Garwood.[1]	Slightly more capacity than Heil or Garwood.[1]	Approximately equal to Garwood.[1]
Salvage value as a function of time	N.A.	N.A.	N.A.

Factor	Heil	Leach	Garwood
Cost, speed and quality of parts service	N.A.	N.A.	N.A.
Manufacturer's provision of pertinent literature	To obtain a complete service manual without extra cost requires the purchase of five bodies.	Probably the same as Heil.[1]	Probably the same as Heil.[1]
Manufacturer's ability to deliver body	Forty-five (45) day delivery generally possible, recommend 45 days after receipt of truck chassis.	N.A. - Probably the same as Heil; however, at this particular time Leach may not be able to make a delivery within 45 days.[1]	N.A. - Probably the same as Heil.[1]
Flexibility in refuse collection	Can handle 1-3 yd^3 bulk storage containers if optional container dumping mechanism is purchased. Can handle only 1-2 yd^3 bulk containers well.[1]	Can handle 1-2 yd^3 bulk storage containers as equipped. Can handle bulky refuse better than Heil or Garwood.[1]	N.A. - Can handle 1-2 yd^3 bulk storage containers. Cannot handle bulk refuse as well as Leach, but as good or better than Heil.[1]
Ease of operation by driver and collectors	Dual controls for tailgate, one each side are available as an optional feature. Because of ease of access of controls crews prefer this unit over Leach but less favorably than Garwood.	Controls for push-out and tailgate are mounted in dual, one each side of compactor by truck cab. Least favorable of three for crew operation.[1]	N.A. Crews prefer using this unit to Heil and Leach because of the ver fast cycling time.[1]

[1]Information not available from equipment manufacturer's literature but obtained by talking with City of Lawrence Sanitation staff or equipment manufacturer's representatives.

[2]N.A. - notation used to mean not available from manufacturer's literature.

Table 14
Information and Specifications
Pertinent to Individual Manufacturer's Units for
Application of the DARE Technique to
Vehicle Chassis Analysis*

Factor	Ford C-800 and LN-750	GMC TE-6500	International Cargostar
Weight hauling capacity of chassis	Gross vehicle weight GVW = 31,000 lb. and 34,000 lb.	Series GVW = 31,000 lb. and 32,500 lb.	CO-1810A Series GVW = 31,000 lb. and 34,000 lb.
Type of collection method employed	Collection method may be either curb, alley, backyard or set-out and set-back service. Since usually one driver and two collectors are used per vehicle all units would offer the same advantages and disadvantages unless special provisions could be made for ordering a dual and/or right side driven unit. This type of unit offers a probable advantage where only curb service is offered.[1]		
Ease of maneuverability and size	Minimum cab to axle length required for 20 yd^3 units is 132 in. for Heil and 135 in. for Leach and Garwood.		
	Tilt cab and short conventional (Louisville series) N.A.[2]	Tilt cab, TE-6750V Wheelbase = 175 in. Cab to axle = 150 in. Overall length = 320 and 1/4 in.	Tilt cab Wheelbase = 149 in. Cab to axle = 132 in. Overall length = 298.5 in. and Wheelbase = 167 in. Cab to axle = 150 in. Overall length = 316.6 in.
Length of haul to disposal site	Same for all units, cost of hauling operation which is considered later, is affected by choice of tire size, transmission and rear axle.[1]		
Cost, speed and quality of parts service	Currently service on parts is considerably better than with GMC or International[1]	Currently service on parts is of poor quality but slightly better than International[1]	Currently service on parts is of poor quality and the worst of all three manufacturers.[1]
Safety of operation	All units offer the following safety or safety related items: Heater and defroster, instrument gauges, oil pressure, ammeter, water temperature and fuel cab marker lights, turn signal and hi-beam indicator lamps, emergency flasher switch and signals, backup lamps, West coast side mirrors, seat belts, hand brake, warning lights, generator charge and oil pressure, windshield wipers and washers, vacuum reserve brake tank with guage and light, speedometer, odometer, safety glass windows, door locks with safety latches.		

*From current literature on tilt cab and short conventional truck chassis of Ford Motor Company, General Motors Corporation and International Harvester company (10,11,12).

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Factor	Ford	GMC	International
Overall vehicle performance and reliability			
a. engine	361 in.^{3} V8, 210 hp or 391 in.^{3} V8, 235 hp	366 in.^{3}, V8, 235hp or427 in.^{3}, V8, 260hp	392 in.^{3}, V8, 236 hp
b. Transmission	Various five speed manual transmissions or a five speed Transmatic (automatic) can be ordered to give the best economy and performance for collecting and hauling refuse.	Various five speed manual transmission are available or a six speed Allison (automatic) can be ordered to give the best economy and performance for collecting and hauling refuse.	Same as GMC.
	Although an automatic transmission may be desirable for certain reasons, the initial cost will be approximately four to seven times greater than that of a standard transmission.		
c. Rear axle	Various axle gear combinations are available for mating with desired transmission. A 22,000 lb axle is available for both 31,000 lb and 34,000 lb GVW ratings.	Various axle gear combinations are available for mating with desired transmission. A 22,000 lb axle is available for both 31,000 lb and 32,500 lb GVW ratings.	Various axle gear combinations are available. It is recommended that a 6.14 rear axle be mated with an Allison 6 speed if an automatic transmission is used. A 22,000 lb rear axle is available for both 31,000 lb and 34,000 lb GVW ratings.
d. Front axle	A 9,000 lb or 12,000 lb. axle is available for 31,000 lb and 34,000 lb GVW ratings respectively.	A 9,000 lb. or 10,500 axle is av available for 31,000 lb and 32,500 lb GVW ratings respectively.	Same As Ford
e. Springs	Minimum as required by stated GVW ratings and equivalent in capacity to both front and rear axle ratings, unless overload springs are ordered.		

Factor	Ford	GMC	International
f. Brakes	Vacuum hydraulic or air brakes are available in different sizes.	Same as Ford.	Same as Ford and GMC.
g. Tires	Various sizes are available- 10.00 x 20 up to 12.00 x 20.	Various sizes are available. 10.00 x 20 front and 11.00 x 20 rears are recommended.	Cast steel spoke and 10 stud disc wheels are available.
h. Wheels	Cast steel spoke and 10 hole disc are available.	Cast steel spoke and Budd 10 stud disc are available. The cast spoke is recommended.	Cast steel spoke and 10 stud disc wheels are available.
i. Steering	Hydraulic power is available as an option.	Same as Ford.	Semi-integral power assist system is an available option.
Frame and Frame reinforcement	Frame reinforcement is available and necessary for compactor body mounting. Front tow hooks are available.	Inverted "L" frame reinforcement is available and necessary for compactor body mounting. Front tow hooks are available.	Same as Ford
Capital Cost	Approximate list price with five speed automatic transmission including standard equipment and the items listed in all categories above excluding federal excise tax, transportation and dealer preparation charges is $10,000 to $11,000.	Approximate list with Allison automatic transmission including standard equipment and the items listed in all categories above excluding federal excise tax, transportation and dealer preparation charges is $10,000 to $11,000.	Same as GMC
Operation and Maintenance	N.A.[2]	N.A.	N.A.

Factor	Ford	GMC	International
Ease of serviceability	C series tilt cabs are no easier to service than GMC or International, however information on the Louisville series indicates that it probably is easier to service than any of the other units.	Is equivalent to Ford C series or International.[1]	Is equivalent to Ford C series or GMC for ease of serviceability.[1]
Salvage value as a function of time	N.A.	N.A.	N.A.
Manufacturer's provision of pertinent literature	N.A. - current literature, specifications and preventive maintenance information probably provided.[1]	N.A. Same as Ford.[1]	N.A. Same as Ford and GMC.[1]
Manufacturer's ability to deliver chassis	N.A. Delivery is usually possible within 45 days.[1]	N.A. Same as Ford.[1]	N.A. Generally the same as Ford and GMC.[1]
Ease of operation by driver and collectors	Louisville series maybe slightly easier to operate than GMC or International[1]	Operation by driver may be slightly more difficult than Ford but equivalent to International.[1]	Equivalent to GMC but maybe slightly more difficult than Ford.[1]

[1] Information not available from equipment manufacturer's literature but obtained by talking with City of Lawrence Sanitation staff or equipment manufacturer's representatives.

[2] N.A. Notation used to mean not available from manufacturer's literature.